

Hydrated Sand Bath & Integrated Solar Thermal- GSHP-Desuperheater & ERV Hybrid Systems

Using Moisture & Temperature Sensors for Optimizing Geoexchange - State-of-the-Art Web-based Monitoring of Integrated Solar Thermal-GSHP-Desuperheater & ERV Systems via Custom Automated Controls - Reducing Installation Costs of Hybrid Systems that Employ Thermal Batteries by as much as 50% - Providing Unprecedented Energy Efficiency for Passive House and Zero Net Energy Homes using ICF Technology and Hydronic-Radiant Heating & Cooling to Capitalize on the Thermal Mass of Concrete

Water & Soil Geoexchange

- Water is at least three times more efficient at exchanging thermal energy than is air or soil.
- A moist clay soil or water saturated sandy soil is substantially more efficient for use in geoexchange systems than dry sandy soils.
- Essentially, due to its relatively high heat capacity and thermal conductivity, water substantially increases both the heat capacity and thermal conductivity of the soil, making it more efficient and more responsive than dry soils which commonly decrease energy efficiency of GSHP systems.
- Thus, water saturated (hydrated or charged) sandy soil has the potential to mimic the geoexchange rate provided by static pond water.

Heat Capacity & Thermal Energy Transfer

- The ability of soils to store and release thermal energy is based on the physical properties of thermal conductivity and thermal diffusivity, both of which are determined by soil composition.
- In physics, thermal conductivity (often denoted k , λ , or κ) is the property of a material to conduct heat. It is evaluated primarily in terms of Fourier's Law for heat conduction.
- Heat transfer occurs at a higher rate across materials of high thermal conductivity than across materials of low thermal conductivity. Correspondingly materials of high thermal conductivity are widely used in heat sink applications and materials of low thermal conductivity are used as thermal insulation. Thermal conductivity of materials is temperature dependent.
- In heat transfer analysis, thermal diffusivity (usually denoted α but a , κ , k , and D are also used) is the thermal conductivity divided by density and specific heat capacity at constant pressure. It measures the ability of a material to conduct thermal energy relative to its ability to store thermal energy.

Heat Capacity & Thermal Transfer of Soils

Thermal Conductivity and Diffusivity of Sand and Clay Soils

Thermal Conductivity (k) - Btu/hr-°F-ft and Thermal Diffusivity (α) - ft²/day

Soil Type	Dry Density	5% Moist	10% Moist	15% Moist	20% Moist				
		k	α	k	α	k	α	k	α
Coarse 100% Sand	120 lb/ft ³	1.2-1.9	0.96-1.5	1.4-2.0	0.93-1.3	1.6-2.2	0.91-1.2	-	-
	100 lb/ft ³	0.8-1.4	0.77-1.3	1.2-1.5	0.96-1.2	1.3-1.6	0.89-1.1	1.4-1.7	0.84-1.0
	80 lb/ft ³	0.5-1.1	0.60-1.3	0.6-1.1	0.60-1.1	0.6-1.2	0.51-1.0	0.7-1.2	0.52-0.90
Fine Grain 100% Clay	120 lb/ft ³	0.6-0.8	0.48-0.64	0.6-0.8	0.4-0.53	0.8-1.1	0.46-0.63	-	-
	100 lb/ft ³	0.5-0.6	0.48-0.58	0.5-0.6	0.4-0.48	0.6-0.7	0.37-0.48	0.6-0.8	0.41-0.55
	80 lb/ft ³	0.3-0.5	0.36-0.6	0.35-0.5	0.35-0.5	0.4-0.55	0.34-0.47	0.4-0.6	0.30-0.45

Coarse grain = 0.075 to 5 mm - Fine Grain less than 0.075 mm

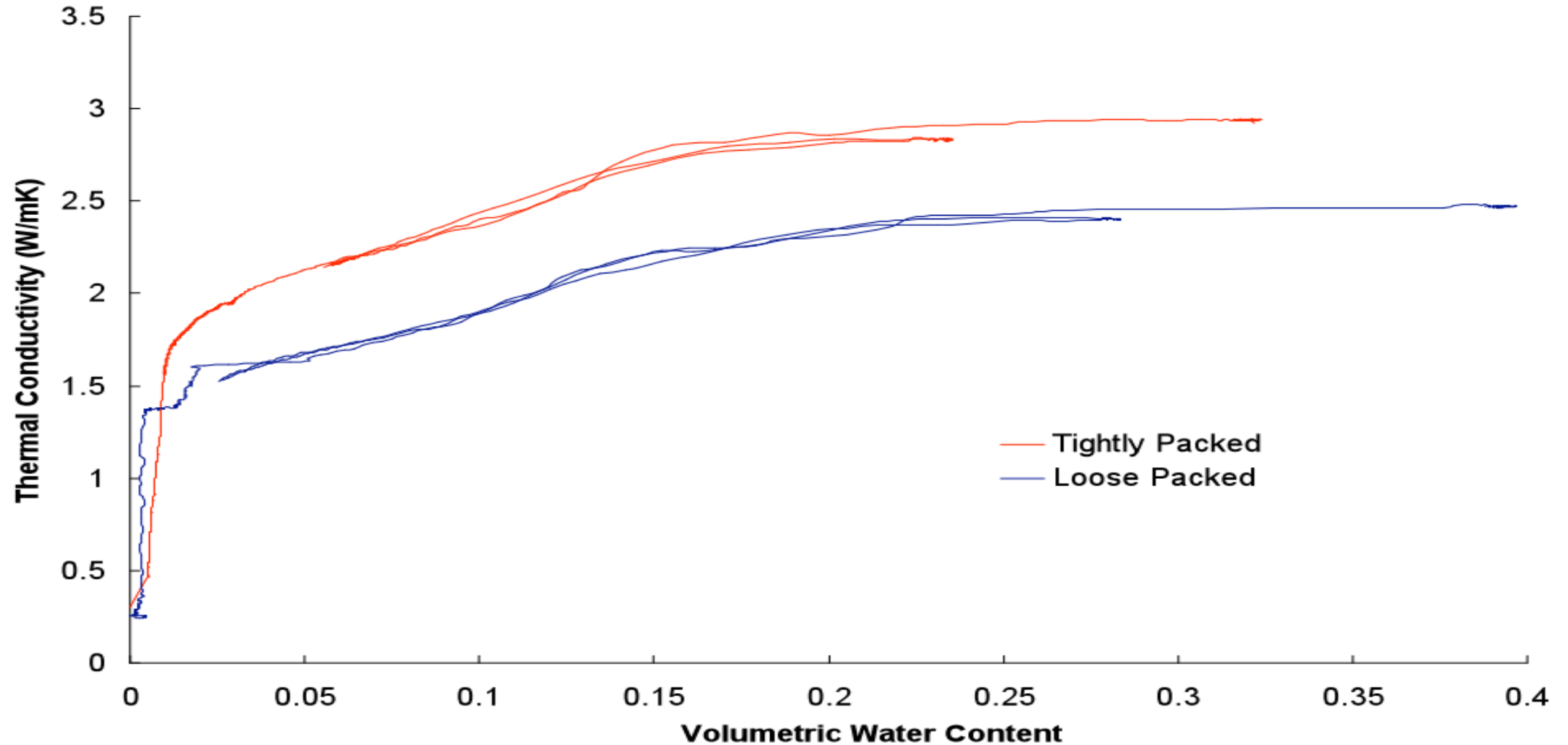
Installation of Hydrated Sand Baths & Slinky Coil Loops in Footing Trenches

- Even though the installation price of a geothermal system can be several times that of an air-source system of the same heating and cooling capacity, the additional costs are returned to the owner in the form of energy savings within 5 to 10 years. For integrated systems ROI can be reduced to less than 5 years.
- System life is estimated at 25 years for the inside components and 50+ years for the ground loop. There are approximately 50,000 geothermal heat pumps installed in the US each year.
- For strategic installation of field loops around the footings of a structure, installation costs of GSHPs can be reduced by over 50%.
- By oversizing geothermal field loops using inexpensive slinky coils, concerns for adverse effects of an earth-coupled basement can be minimized.

High Thermal Conductivity & Low Thermal Diffusivity

- The ideal soil for geothermal/ground loops is a soil of high thermal conductivity and low thermal diffusivity (high heat capacity) so that heat transfers quickly and the soil has increased thermal storage capability.
- With 40% porosity, coarse sand can hold up to 40% water. Water has a relatively high heat capacity and medium thermal conductivity which is ideal for use in a thermal battery system.
- Whereas air has a thermal conductivity of 0.024, water increases thermal conductivity by 23 fold, e.g., to 0.563 BTU/hr-°F-ft. At 20% moisture sand has a thermal conductivity of 1.4 to 1.7 BTU/hr-°F-ft.
- A hydrated sand bath surrounded by a clay soil could allow for optimizing thermal conductivity and thermal diffusivity, particularly in conjunction with regulating soil moisture and temperature.

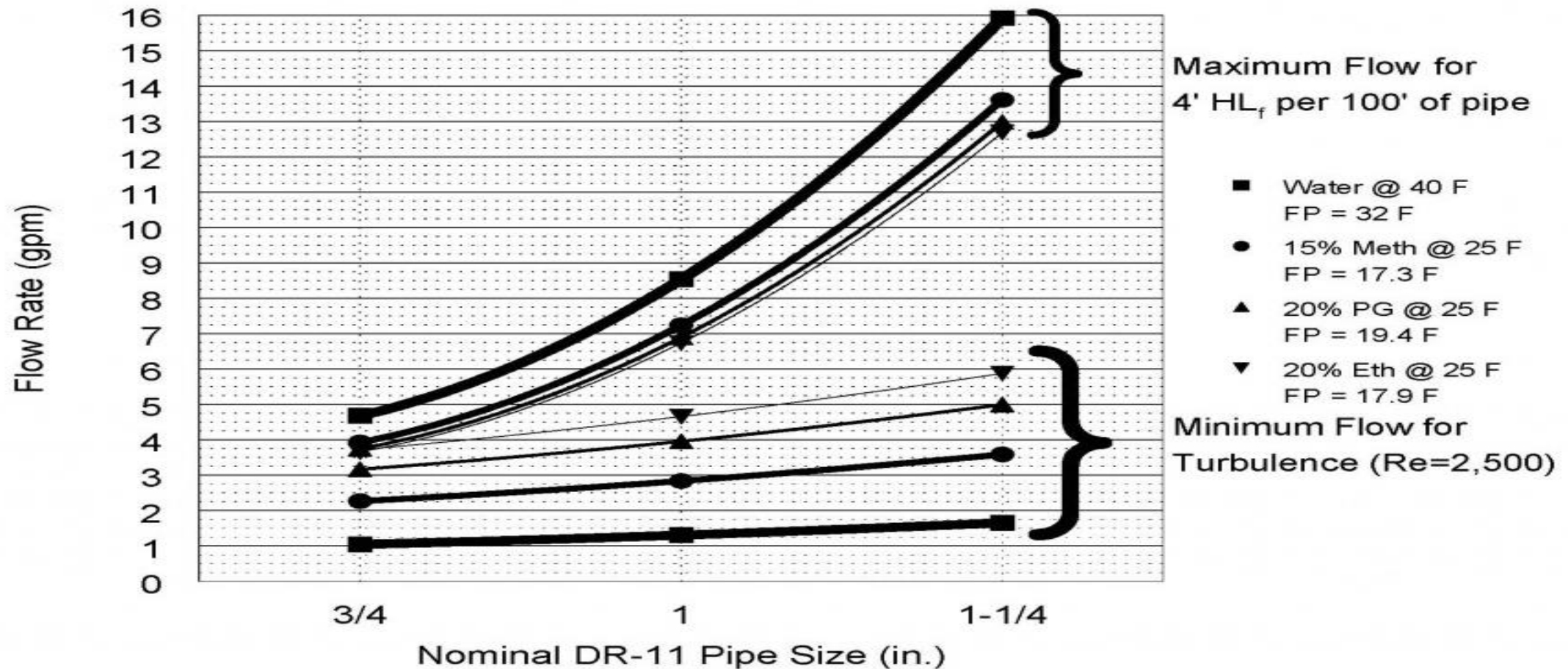
Thermal Conductivity of Hydrated Sand



Optimal Moisture & Temperature

- Interestingly, tightly packed sand increases thermal conductivity of soils.
- Though increasing moisture levels to 25% substantially increases thermal conductivity, subsequent increases in moisture up to 40% has a nominal effect on thermal conductivity while slightly decreasing diffusivity.
- Increasing soil temperature from 50°F to 70°F could substantially increase thermal conductivity of hydrated sand, but would also increase thermal diffusivity, resulting in decreasing heat capacity.
- Heat capacity of hydrated sand baths will be about 75% less than pure water bath as sand holds less heat than water. However the increased conductivity offered by the combination of sand and water should make this a worthwhile sacrifice, particularly in conjunction with the heat capacity of the surrounding soil.

Geothermal Emitter - Field Loop or Slinky Loop Flow Rates & Tube Sizes



Hydrated Sand Baths

- In contrast to 100% fine grain clay soil with 20% moisture content and 0.6 to 0.8 BTU/hr-°F-ft thermal conductivity, hydrated sand baths provide 40% porosity with a thermal conductivity of 1.4 to 1.7 BTU/hr-°F-ft at 20% moisture.
- This results in more than doubling thermal conductivity using sand baths at 20% moisture. If the moisture content is increased to 40%, this should effectively double the thermal conductivity of the hydrated sand bath.
- Moisture and temperature sensors in sand baths allow for effectively regulating thermal conductivity using valve controls and drip lines. This innovative approach can provide unprecedented energy efficiency via water to water GSHPs.

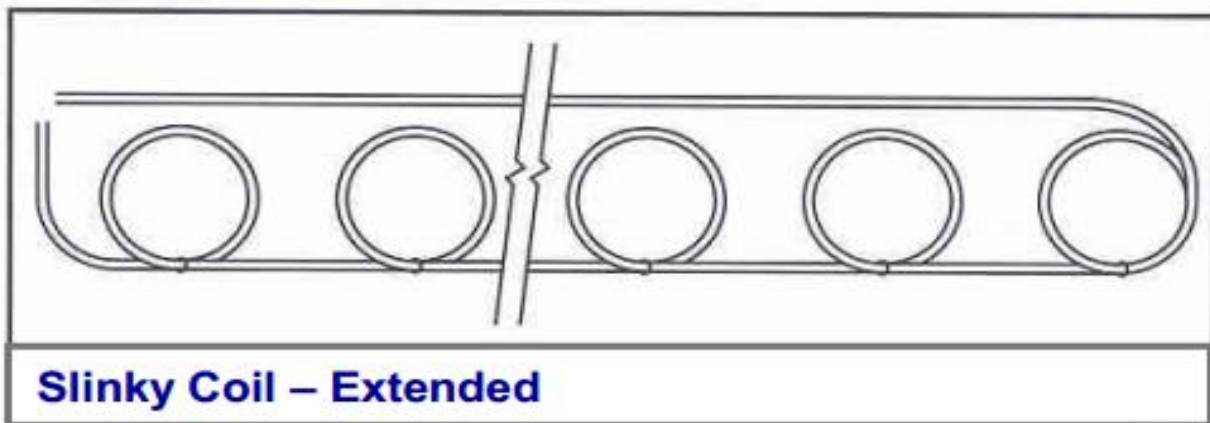
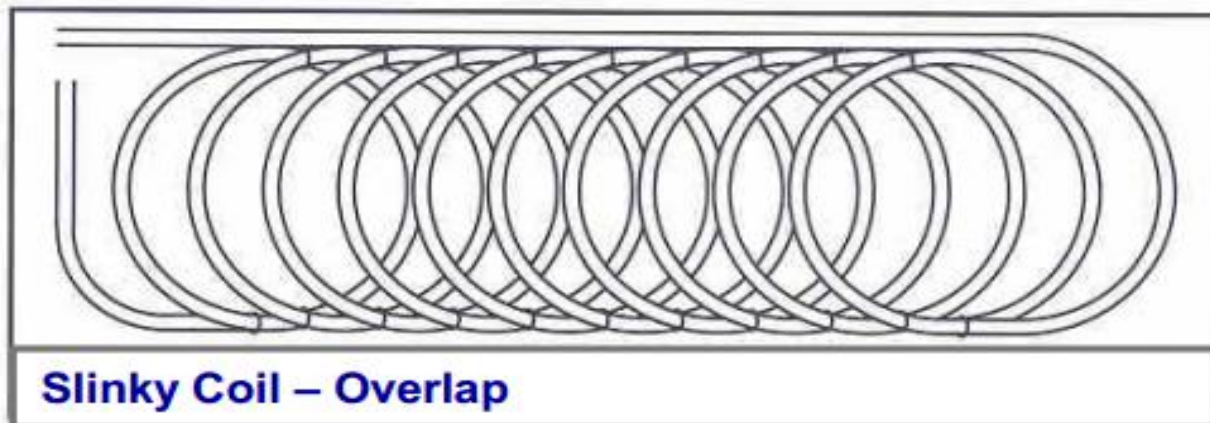
Sand Bath Loop Field

- Installing slinky field loops in a sand bath around the footing of a structure with a moisture barrier in place to protect the structure provides the potential to mimic the geoexchange performance achieved from pond loops.
- This approach using a drip line and moisture sensors connected to an automated control that operates the drip-line valve provides the capability of maximizing geoexchange in almost any soil type.
- Hence, investment in field loop tubing can be minimized, e.g., as little as 400' of overlapped slinky $\frac{3}{4}$ " tubing per ton of heating or cooling capacity buried at 8-10' deep should be sufficient for hydrated sand bath applications.

Selection of Tube Size for Slinky Field Loops

- Though 3/4 inch tubing is typically utilized for geoexchange field loops, 1 inch and 1.25 inch tubing are also commonly used and can allow for reducing pipe length depending on the heat exchange capacity of the soil or sand bath.
- Though the 1 inch and 1.25 inch size tubes are more difficult to work with when installing slinky loops, they can be used.
- The larger tubes are advantageous in terms of increasing flow, reducing friction, pump head loss, and electricity used by circulation pumps.
- Designing geoexchange loops with 2 tons per slinky loop allows for reducing the number of field loops and decreasing cost of manifolds.

Slinky Loop



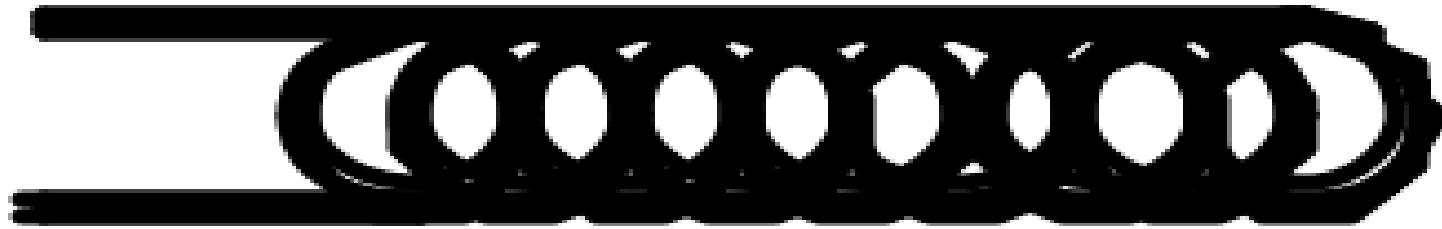
- **To Produce 1 ton of capacity:**
 - Trench length – typically 125 feet
 - Pipe length – out & back = 700 feet



Tube Size & Length of Slinky Loops

- Since the circumference of a circle = πd (3.1416 x Diameter of 6 ft.) = 18.8496 ft. per slinky coil.
- Based on heat exchange using 0.75 inch tubing, about 400 ft. would be required per ton of heating and cooling capacity for hydrated/charged soils. With a 24 inch overlap of coils, that would require only 20 ft. of slinky loops per ton.
- Depending on the heat exchange of the soil and system design, 1.25 inch tubing could reduce the slinky loops to as little as 10 ft. per ton.
- 200 ft. of 1.25 inch tubing comes in about a 5-6' diameter rolls. 7' footing trenches would allow for stretching the slinky coils out and tying them in place using a 6-7' trench next to the footings.

Slinky Coil Pitch (ft. of tubing/ft. of trench)

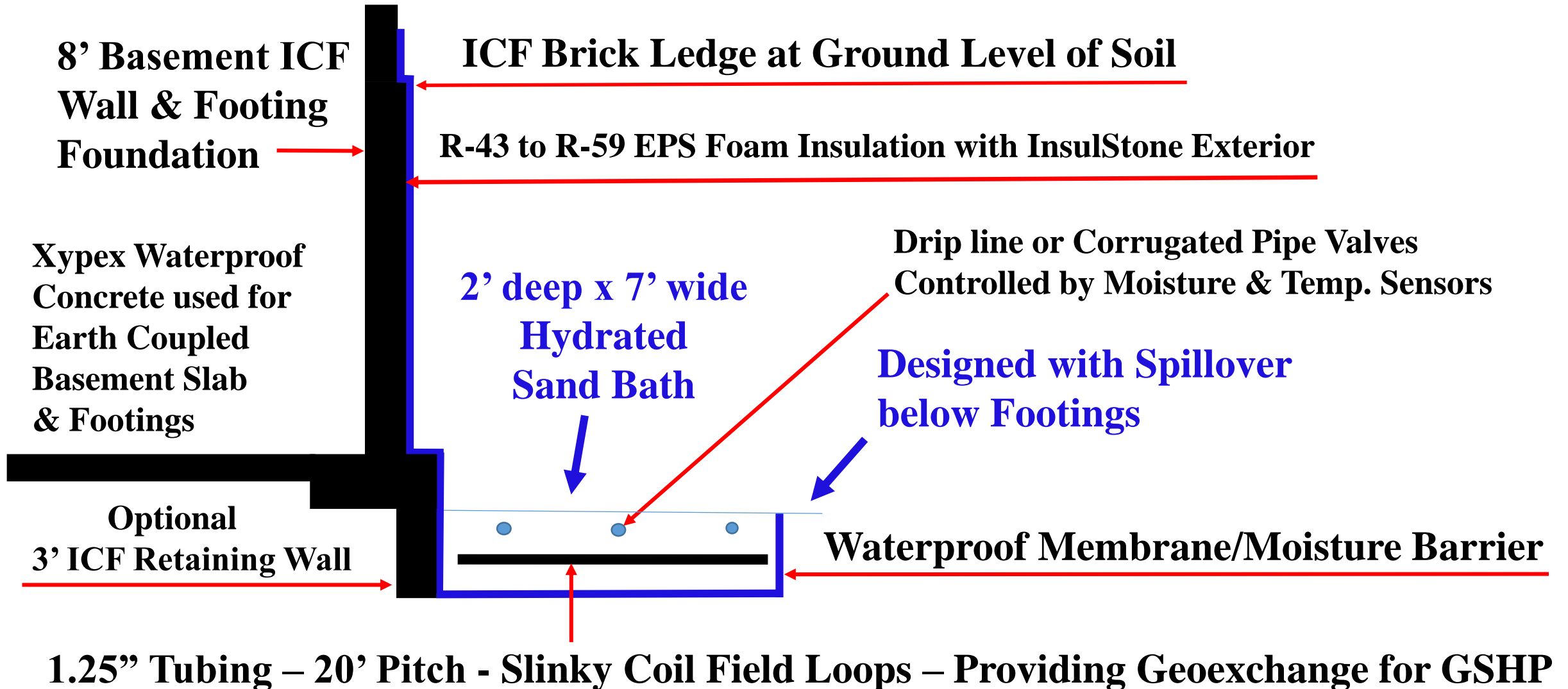


6' Diameter Coil - 40 Pitch Slinky



6' Diameter Coil - 20 Pitch Slinky

Sand Bath Field Loop Design



Less than 25% Reduction in Thermal Capacity

- Since thermal conductivity is regulated by soil moisture levels, strategically installing the hydrated sand bath around the footings of a structure should not significantly decrease the thermal capacity or performance of the geothermal field loops.
- The majority of the soil profile located under a structure does not receive precipitation, nor is it warmed by the sun.
- Thus, the amount of thermal energy available under a structure would be substantially less than the surrounding soil which comprises over 75% of the thermal energy available from the earth.

Strategic Design

- Depending on design of the geothermal field loops and heat exchange system around the footings of a structure, it could have an adverse effect on an earth-coupled basement and draw heat from the structure and the earth under the structure.
- For insulated basement floors it would be interesting to model/determine the effect that geothermal loops could have on heating and cooling the structure vs. an earth coupled basement? Typically, unless the geothermal system is designed to maintain soil temperatures above 60 °F, this could result in cold basement floors for earth coupled systems.
- Though the concept of a hydrated sand bath doesn't increase the thermal energy available in the soil, it can enhance thermal conductivity similar that achieved through installation of slinky coils in a pond. Thus, for strategically designed geothermal field loop and heat exchange systems, there is potential for hydrated sand baths and hydrated soils surrounding the sand baths to substantially enhance responsiveness and load capacity of the geothermal system.

Moisture & Temperature Sensors

- Moisture and temperature sensors could be placed in the hydrated sand baths, or simply use temperature sensors on the supply side of geothermal field loop where it connects to the GSHP.
- Though the latter method wouldn't provide direct information pertaining to the moisture level of the sand bath, a drop in temperature would indirectly suggest either a drop in moisture and thermal conductivity levels, and/or a drop in the available thermal energy in the soil profile.
- There are obvious advantages in regards to convenience of locating sensors on readily accessible portions of the geothermal system.

Thermal Conductivity and Diffusivity of Sand and Clay Soils

Thermal Conductivity (k) - Btu/hr-°F-ft and Thermal Diffusivity (α) - ft²/day

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	80 lb/ft ³	0.5-1.1	0.60-1.3	0.6-1.1	0.60-1.1	0.6-1.2	0.51-1.0	0.7-1.2	0.52-0.90
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	100 lb/ft ³	0.5-0.6	0.48-0.58	0.5-0.6	0.4-0.48	0.6-0.7	0.37-0.48	0.6-0.8	0.41-0.55
	80 lb/ft ³	0.3-0.5	0.36-0.6	0.35-0.5	0.35-0.5	0.4-0.55	0.34-0.47	0.4-0.6	0.30-0.45

Coarse grain = 0.075 to 5 mm - Fine Grain less than 0.075 mm

Geothermal Field Loop Lengths

- The table below provides recommendations for ground loops in the Tennessee Valley Authority service area and beyond. The values use results from this TVA sponsored project coupled with a previous Alabama Power project and the resulting recommendations for Alabama (Kavanaugh, 1991).
- The length of the trench or bore must be based on the amount of pipe in the trench, burial depth, and average ground temperature and conductivity. The table provides extremes of pipe length per length of trench from 10 ft/ft (i.e. 1000 ft. of pipe in a 100 ft. long trench) to 2 ft/ft.

Geothermal Field Loop Lengths cont.

- The table was developed for an average burial depth of 5 ft. and $\frac{3}{4}$ " high-density polyethylene (HDPE) pipe. The extremes of normal ground temperature are 44°F for the northern continental US and 70°F in southern USA (not including southern Florida and Texas and all of Hawaii).
- These lengths should provide a maximum loop temperature of 90°F entering the heat pump in normal applications. In homes with excessive run times this temperature will be 3° to 5°F higher.
- The table also includes recommendations for vertical ground loops in ft. of bore per ton for $\frac{3}{4}$ " and 1-1/4" HDPE, which will operate about 5°F cooler than the horizontal loops.

Table 1. Recommended Lengths of Trench or Bore Per Ton For GCHPs

Multiply length of trench by pitch to find required length of pipe.

See Tables 4 and 5 for Thermal Conductivity of Soils and Rocks.

	Pitch	Ground Temperature - °F						
Coil Type (See Figure 1 for Details)	Ft. of Pipe per Ft. Trench (or Bore)	44 to 47° F	48 to 51° F	52 to 55° F	56 to 59° F	60 to 63°F	64 to 67°F	68 to 70°F
Horz. 10-Pitch Slinky	10	125	120	115	120	125	150	180
Horz. 6-Pipe/6-Pitch Slinky	6	180	160	150	160	180	200	230
Horz. 4-Pipe/4-Pitch Slinky	4	190	180	170	180	190	220	260
Horz. 2-Pipe	2	300	280	250	280	300	340	400
Vertical U-tube (3/4" Pipe)	2	180	170	155	170	180	200	230
Vertical U-tube (1" Pipe)	2	170	160	150	160	170	190	215
Vertical U-tube (1¼" Pipe)	2	160	150	145	150	160	175	200

Table 1 based on $k=0.6$ Btu/hr-ft-°F for horizontal loops and $k=1.2$ Btu/hr-ft-°F for vertical loops and an annular fill/grout conductivity of 0.85 in vertical loops. For other conditions:

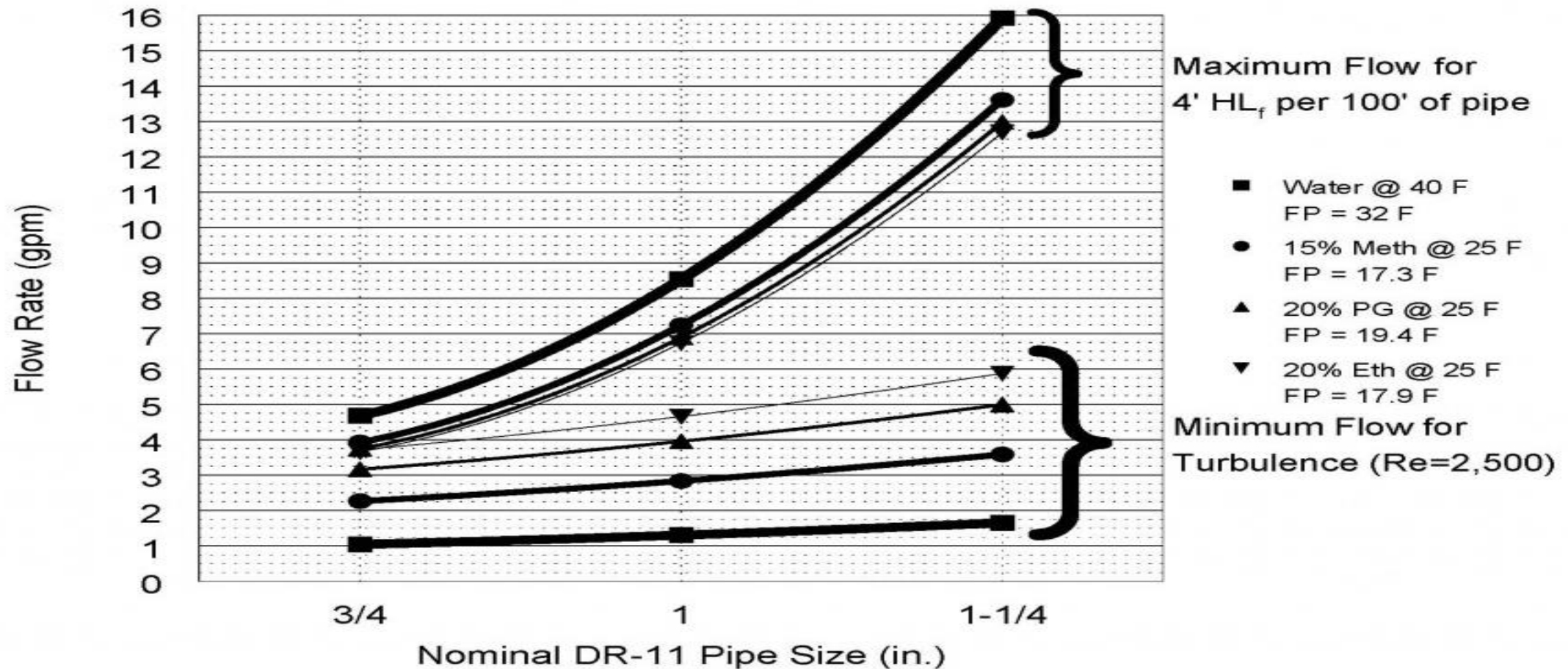
$$L/\text{Ton}(\text{Corrected}) = L/\text{Ton}(\text{Table 1}) \times CF(k\text{-ground}) \times CF(k\text{-annulus})$$

Ground Therm. Cond. (Btu/hr-ft-°F)	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Horz. Loop, CF(k-ground)	1.22	1.0	0.89	0.82	---	---	---	---	---
Vert. Loop, CF(k-ground)	---	---	1.23	1.10	1.0	0.93	0.87	0.83	0.79
Annulus Ther. Cond. (Btu/hr-ft-°F)	0.4	0.6	0.8	0.85	1.0	1.2	1.4	No Correction for Horz. Loop	
Vert. Loop, CF(k-annulus)	1.2	1.08	1.01	1.0	.98	.93	0.91		

Sand Bath Design Considerations

- There are three critical design factors for the sand bath: Heat capacity, thermal conductivity and thermal resistivity.
- Thermal conductivity should range from 1.4 to 1.7 according to literature.
- Heat capacity will be determined by porosity ratios. Total capacity will be about 75% less than a pure water bath as sand holds less heat than water. However, the increased conductivity offered by the combination of sand and water will make this a worthwhile tradeoff.
- Thermal resistance in the case of the hydrated sand bath will be due primarily to pipe resistance. Running two parallel slinky loops will reduce this resistivity by a factor of two.

Geothermal Emitter - Field Loop or Slinky Loop Flow Rates & Tube Sizes



Water vs. Anti-freeze Solutions

- The above chart reveals that thermal heat exchange is highest with pure water vs. using anti-freeze solutions.
- This allows for substantially reducing flow rate which decreases head loss and circulation pump power required.
- Strategically over-sizing slinky loops in hydrated sand baths for 1.25 inch tubes has potential for optimizing heat exchange while minimizing head loss.
- This would result in minimizing temperature differential for the geothermal loop, thus optimizing COP and EER for the GSHP system.
- This is particularly true for integrated solar thermal – GSHP system.

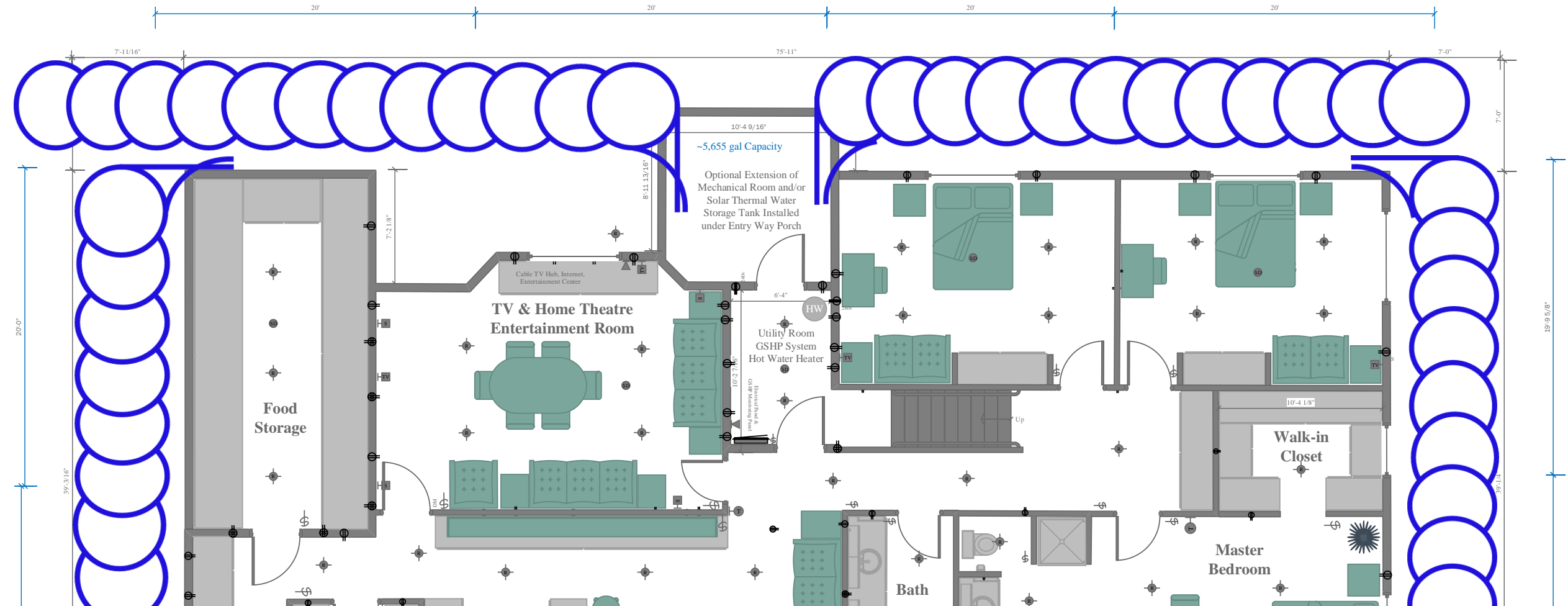
Geothermal Trench Lengths per Ton of Capacity for 1.25 inch Emitter Tubing in Footing Trench

		Ground Temperature °F						
Loop Type & Size – 1.25” tubing	Pitch	44-47	48-51	52-55	56-59	60-63	64-67	68-70
6’ Diameter Slinky Coils – 7’ Wide Trench - Horizontal Loop Field - 20 Pitch	20	16	15	14.5	15	16	17.5	20
6’ Diameter Slinky Coils – 7’ Wide Trench - Horizontal Loop Field - 40 Pitch	40	8	7.5	7.25	7.5	8	8.75	10
Straight Line – 1 Loop around Structure - 4’ trench	1	320	300	290	300	320	350	400
Straight Line – 2 Loops around Structure - 4’ trench	2	160	150	145	150	160	175	200

PHMH-2512

GSHP Geoexchange Slinky Loop Field Installed Around Basement Footings Using a Moisture Barrier and Sand Bath

7' Wide Trench by 8-10' Deep for 20' per ton Slinky Coil Loops



Geothermal Loop Head Loss

- GeoPro's Excel spreadsheet macro calculates head loss of 7.12 ft. (0.89/100 ft.) for 2 ton loops using 1.25" emitter tubes and 800' loop lengths at a flow rate of 6.5 GPM for water (no antifreeze required for a solar thermal drainback system and strategic geothermal design). Increasing flow rate to 8.0 increases the head loss to 10.16 ft. for the supply loop.
- Two of these loops connected to a manifold will be utilized for meeting 2nd stage peak heating capacity via the GSHP and also for supplying 3rd stage pre-heating and pre-cooling fan coils, and for hydronic supply to the air handler heating and cooling coils.
- A solar thermal-GSHP system head loss of ~12 ft. and a flow rate of 6.5 GPM will require a circulator pump ranging from 0.1 to 0.167 hp for the supply loop of the integrated solar thermal - GSHP- ERV and air handler system.

Electronic Commutated Motors

- Variable flow-rate reduces energy consumption.
- By reducing flow-rate ECM circulation pumps can increase the temperature difference between water leaving and entering the integrated solar thermal-GSHP/buffer tank system.
- EMC circulation pumps compensate for the fact that conventional circulation pumps are significantly oversized.
- Advanced ECM circulators automatically determine the lowest possible operating efficiency point to meet changing system demands.
- ECM pumps and fan-coil/air handler motors allow for reducing energy consumption of HVAC systems by 40-82% according to case studies.

40-85% Reduction in Energy Consumption

- Out of the box, an ECM circulator will yield the same flow rate while consuming 50% less energy over a traditional induction-type circulator.
- Some ECM circulators, such as the Grundfos ALPHA and Taco HE-2, use smart technology and integrated logic boards to “learn” the system’s usage patterns in order to boost the standard 50% energy savings into the 70-85% range.
- As the valves in the different sections open or close with rising or falling demand, these smart circulator pumps automatically ramp up or down to meet the load.
- Innovative system designs may allow for using only one ECM circulator pump for the supply and distribution loops of the HVAC system provided head loss can be maintained below ~12 ft.

Wholesale Distributors of Grundfos

- Grundfos ALPHA ECM circulation pumps can be economically purchased online through a variety of retail and wholesale distributors:
 - [Global Industrial](#)
 - [Locke Well & Pump Co.](#)
 - [eBay](#)
 - [eBay - pextubing](#)
 - [Pump Products](#)
 - [www.pexsupply.com](#)
- Conventional circulation pumps, which are often 90% less expensive and provide similar energy consumption for passive house and geothermal applications, are often cost effective alternatives.

Grundfos vs. Taco Models

- HVAC geothermal systems can be designed with 6.5 GPM flow and up to 14.5 ft. head loss (by running fan coils in parallel or in separate loops) in order to minimize cost of circulation pumps purchased online from www.pexsupply.com:
 - Taco 0015-MSF2-IFC cast iron 3 speed with internal flow check - 1/20 HP, operates from 0-18 GPM with up to 21 ft. head loss. Purchase price \$82.
 - Grundfos UPS15-58C cast iron 3 speed – 1/25 HP operates from 10-17 GPM with up to 19.5 ft. head loss. Purchase price \$94.75. \$14.60 annual energy savings.
 - Taco HEC-2 cast iron variable speed ECM with internal check valve – operates from 0-15.5 GPM and 0-15 ft. head loss. Purchase price \$175. \$56.72 annual savings.
 - Grundfos ALPHA 15-55 F 165 cast iron ECM variable speed - 1/15 HP operates from 0-21.5 GPM and 0-19 ft. head loss. Purchase price \$160 (purchasing groups of 3). \$55.07 annual energy savings.

ECM Variable Speed Circulation Pumps

- At up to an 85% increase in energy efficiency over the Taco 015 model, the ROI for the Taco Bumble Bee (Model HEC-2) or Grundfos ALPHA 15-55 ECM variable speed pump models would be less than two years for variable speed applications.
- However, if supply and distribution loops are designed so that constant flow and head loss is achieved, then there is no advantage to investing in variable speed pumps.

Grundfos Performance/Cost Comparison

	Taco 007-BF5	Grundfos ALPHA15-55SF	Grundfos UPS15-55SFC
SYSTEM:	Open	Open	Open
Pump Body:	Bronze	Stainless Steel	Stainless Steel
Max Flow (GPM):	23.00	21.50	25.00
Max Head:	10.00	17.00	18.00
Max Working Pressure (PSI):	125	150	145
Max Watts:	87.40	45.00	87.00
HP:	1/25	1/15	3/25
Port to Port Length:	6-3/8"	6-1/2"	6-1/2"
Flange Size/Connection Type:	2-Bolt Flange	2-Bolt Flange GF 15/26	2-Bolt Flange*
Est. Annual Energy Costs¹:	\$49.65	\$8.95	\$49.42

¹Energy costs calculated on pump operating 13 hours a day, 230 days a year. Dollar amount based on \$0.19 kWh.

Grundfos Performance/Cost Comparison

	Taco 0015-MSF2-1IFC	Grundfos ALPHA15-55F	Grundfos UPS15-58FC
SYSTEM:	Closed	Closed	Closed
Pump Body:	Cast Iron	Cast Iron	Cast Iron
Max Flow (GPM):	18.00	21.50	17.00
Max Head:	21.00	17.00	19.50
Max Working Pressure (PSI):	125	150	145
Max Watts:	112.70	45.00	87.00
HP:	1/20	1/15	1/25
Port to Port Length:	6-1/2"	6-1/2"	6-1/2"
Flange Size/Connection Type:	2-Bolt Flange-R	2-Bolt Flange GF 15/26	2-Bolt Flange GF 15/26
Est. Annual Energy Costs¹:	\$64.02	\$8.95	\$49.42

¹Energy costs calculated on pump operating 13 hours a day, 230 days a year. Dollar amount based on \$0.19 kWh.

Potential Return on Investment: PSC vs. ECM

- The ROI can be calculated using the following equation:

$$\text{ROI (in years)} = (\text{Project Cost}) / (\text{Energy Savings})$$

- Included in the project cost are the costs associated with the purchase of the motors and the labor expenses. The project cost was \$160 per motor replaced.
 - State Return on Investments (years)
 - Georgia 2.6 - (\$0.0914/kWh) [similar in price to residential Idaho Power rate)
 - New York 1.4 - (\$0.1672/kWh)
 - Massachusetts 1.3 - (\$0.1867/kWh)

Project cost is for example purposes only. True project cost may be higher or lower than given, particularly is ECM pumps and fan motors are purchased via wholesale outlets.

PHMH-2512 Configuration – 11,000 Btu/hr. Peak Heating - ~9,000 BTU/hr. Peak Cooling

- With solar thermal providing 70-90% of peak heating capacity, the 2nd stage GSHP system will be used minimally.
- A one ton GSHP will be integrated with the RecoupAerator 200DX ERV, providing 96% heat exchange efficiency.
- Solar thermal and geothermal loops will enhance efficiency of forced air heating, cooling, and regulation of humidity via pre-heating and pre-cooling coils.
- Relatively small slinky loop lengths, 20 pitch provided via 6' diameter loops, all water system in hydrated sand baths with 1.25 inch emitters will minimize head loss, flow rate, and power consumption for circulation pumps while optimizing heat exchange efficiency.

Hydronic-Radiant Distribution Loop

- The design of the hydronic-radiant distribution loop and delivery system will be simplified and balanced with the supply of the geothermal loops.
- Due to relatively low cost (\$0.51/ft.) of 1.25 inch emitter tubing, two to four loops will be utilized for an over-sized sand bath, providing 1-2 ton capacity per loop.
- Similarly, the radiant distribution system will be comprised of 7/8" pex tubing placed on 8 inch centers and embedded in a 4" concrete slab.
- This integrated solar thermal – GSHP – ERV – hydronic-radiant floor and 2nd stage ERV/air handler system will allow for minimizing temperature differentials for EWT and LWT, thus increasing COP and EER by up to two-fold.